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13. ABSTRACT *(Maximum 200 words)*

The electromagnetic scattering from the sea surface at small grazing incidence is being examined numerically. Two numerical approaches, both extentions of the standard moment method (MM), are being used. The first is a hybrid approach that extends MM using the geometrical theory of diffraction. It has been used to examine the multipath scattering from a breaking ocean wave that may lead to sea-spike events and the effects of surface self-shadowing on distributed-surface scattering. The second approach is a periodic-surface implementation of the moment method. It has been used to examine the ability of the effects of finite surface conductivity on the scattering from wind roughened water surfaces.

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NUMERICAL INVESTIGATION OF RADAR SCATTERING FROM THE SEA SURFACE AT SMALL GRAZING ANGLES

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LONG-TERM GOAL

The research program focuses on the understanding electromagnetic scattering from the ocean surface at small illumination grazing angles. The long-term goal is to investigate the validity of existing distributed-surface, edge-diffraction, multi-path, and shadowing scattering theories when applied to the ocean surface small grazing angles.

SCIENTIFIC OBJECTIVES

The short-term objective is to numerically characterize the electromagnetic scattering from modeled and measured water surface profiles and compare the results with existing scattering models.

APPROACH

The scattering from measured and modeled water surfaces is being calculated using two distinct extensions of the standard moment method (MM) that allow application at arbitrarily small grazing angles. The first extended method is a hybrid approach that extends the moment method using the geometrical theory of diffraction (GTD). The front and back faces of the modeled surface are extended to infinity, eliminating any nonphysical edges that affect the calculated scattering. Thus, no illumination weighting function is needed to prevent the edge effects as in the standard moment method. The results of GTD are used to derive single basis functions that represent the surface currents on the extensions to infinity, minimizing the computational expense of the infinite surface representation. The second extension to the moment method used is a periodic surface implementation. The periodic representation of the modeled surface extends it to infinity, again eliminating the need for an illumination weighting function

WORK COMPLETED

The MM/GTD hybrid approach has been used to find the scattering from a surface profile modeling a breaking water wave. Impedance boundary conditions were used to represent the finite conductivity of sea water. The predictions of the multiple-bounce interference model including Brewster angle damping have been directly compared with the numerical results. This numerical approach has also been used to find the contributions of small-scale roughness in shadowed regions to the total backscatter at small grazing angles with sea water surfaces.

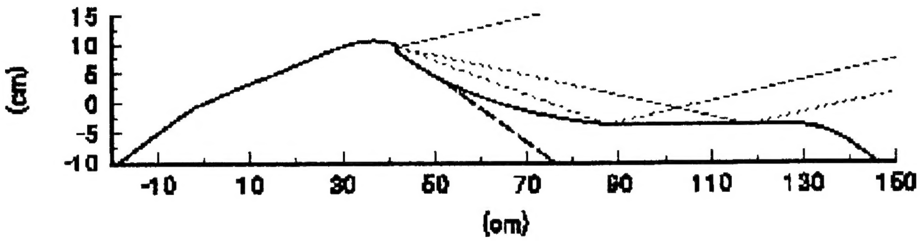

Figure 1

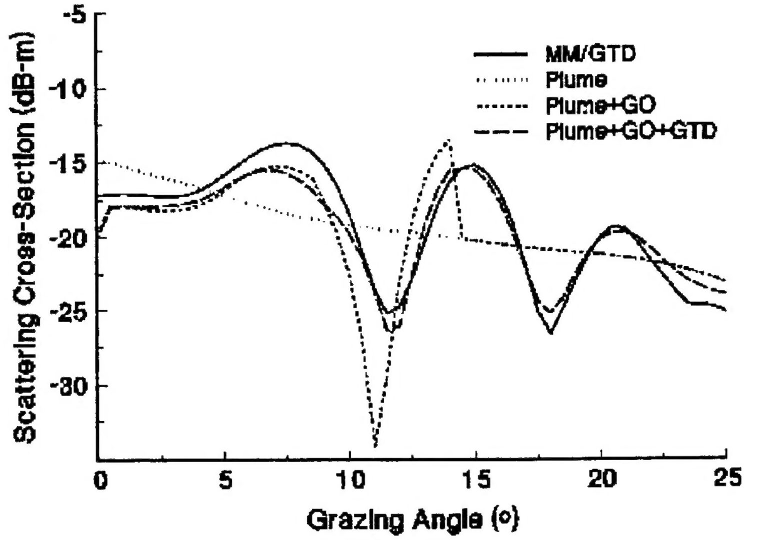

Figure 2

The periodic surface implementation of the moment method was extended to allow the application to finite conductivity as well as perfectly conducting surfaces using impedance boundary conditions. It has been used to find the scattering from directly measured profiles of wind-roughened water.

RESULTS

The modeled breaking-wave surface profile is shown as the solid line in Figure 1. The calculated scattering from this surface at 9 GHz and assuming sea-water dielectric properties (a complex dielectric constant of 60 - j35) is shown as the solid line in Figure 2. Strong oscillations appear in the response, suggesting that direct scattering from the breaking plume is interfering with multipath scattering that scatters from the plume and reflects of the front face, as predicted by the multiple-bounce model of Trizna (1997). To confirm this, the total backscatter was calculated from geometrical optics (GO). The multipath reflection points were identified using GO ray racing. The reflection paths identified at 10 degrees grazing are shown by the short-dashed lines in Figure 1. Each reflection off the front face actually represents three backscattering paths: the energy that scatters off the plume and reflects off the front face, the reciprocal path that reflects off the front face and scatters from the plume in the backscatter direction, and a double-bounce path that reflects off the front face, scatters off the plume back to the front face, and then reflect from the front face in the backscatter direction. The scattering along these paths plus the direct backscatter from the plume were combined to give the total scattering. Since the plume is too small to be treated with an optical approach the bistatic scattering pattern was calculated numerically using the truncated surface represented by the long-dashed line in Figure 1. The curvature and finite conductivities of the surface were taken into account in the calculation of the reflections from the front face.

The backscattering from the plume alone is shown as the dotted line in Figure 2. The GO multipath reflections are added in the short-dashed curve of Figure 2. Below 14 degrees grazing the GO interference pattern matches the MM/GTD scattering reasonably well. However, above 14 degrees there are no reflection paths that give backscatter, so the GO results shown no interference and there is a discontinuity in the scattering at 14 degrees. This behavior results because the radius of curvature of the front face of the wave changes rapidly at x = 95 cm, leading to shadow boundaries for both reflection points shown in Figure 1 that are crossed at 14 degrees grazing. Energy therefore must be diffracted from this point to account for the reflection boundaries. The diffracted energy was calculated using uniform GTD for a 180 degree wedge with differing face curvatures. The finite conductivity of the surface was considered using the heuristic approach of Luebbers (1988). The scattering when this diffraction is included is shown in Figure 2. Very good agreement with the MM/GTD scattering is obtained at all grazing angles. Similar agreement was achieved at horizontal polarization (not shown).

The periodic-surface moment method was used to find the backscattering from surface profiles derived from direct slope measurements of wind-roughened wave-tank water surfaces. The results at 30 GHz are shown in Figure 3. The scattering when a perfectly conducting surface is considered is shown as a solid line, while the sea-water surface scattering is shown as a dashed line. As expected, horizontally polarized backscattering is only slightly affected by the conductivity change, while vertically polarized scattering drops much more dramatically, particularly at the highest incidence (small grazing) angles. An effort is underway to compare the predictions of the two-scale scattering model with the numerical calculations.

The hybrid MM/GTD numerical approach was used to find the effects of shadow-region roughness on small-grazing backscattering from a sea water surface. Previous results (West, 1997) showed that when a perfectly conducting surface is considered the shadow-region contribution is much greater at vertical polarization than at horizontal polarization. The calculated backscattering when a surface dielectric constant of 60 - j35 is shown in Figure 4. The rough-in-shadow and smooth-in-shadow (no shadow-region roughness) curves deviate at approximately the same grazing angles for both polarizations, indicating that the relative contributions of the shadow-region roughness are approximately the same in each case.

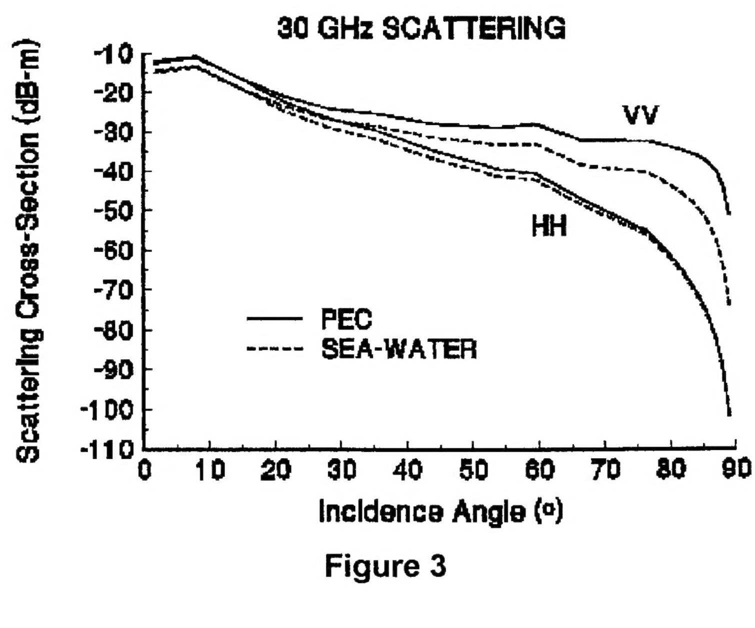

Figure 3

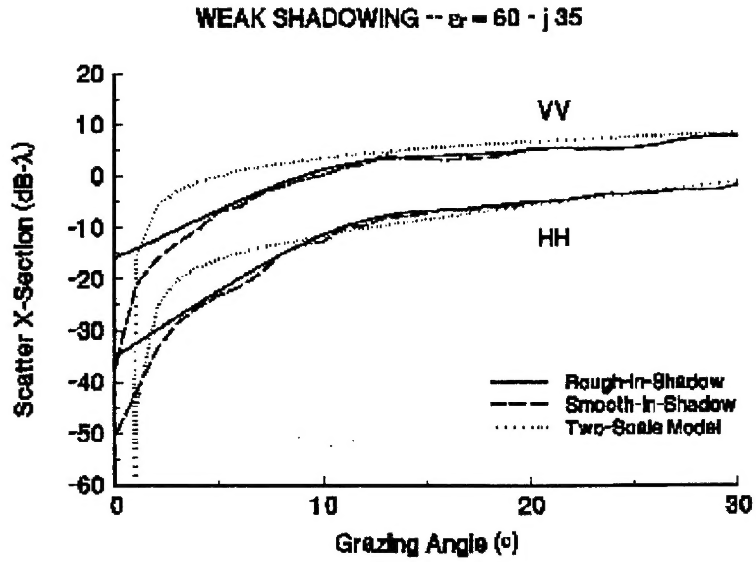

Figure 4

IMPACT/APPLICATION

The breaking-wave model calculations confirm that multipath interference in the scattering from breaking waves can be predicted using a ray-optical approach. However, the multipath may result from effects that are more complicated that direct Fresnel reflection. The enhancements of the periodic-surface moment method will allow the predictions of distributed-surface scattering theories to be tested when applied to finite conductivity surfaces at grazing angles approaching zero. The shadowing study demonstrates that shadowing theory will give acceptable results at lower grazing angles when applied to the sea surface at vertical polarization than is predicted using perfectly conducting surfaces

RELATED PROJECTS

The breaking-wave model profile was provided by Mark Sletten of NRL. The wind-roughened surface profiles used with the periodic-surface moment method were provided by Jochen Klinke of the Scripps Institute of Oceanography. The numerical codes are currently being applied to surface profiles provided by Ken Melville of Scripps and Jim Duncan of the University of Maryland.

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